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BY: _____

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SPECIFICATION

To all whom it may concern:

Be It Known, That We, **Timothy D. Thompson**, a citizen of the United States of America, residing at 677 Poudre Place, Windsor, Colorado 80550 and **Christopher D. Paulson**, a citizen of the United States of America, residing at 3009 Avena Court, Fort Collins, Colorado 80528, have invented certain new and useful improvements in **"METHOD AND APPARATUS FOR TRANSFERRING DATA BETWEEN A FASTER CLOCK DOMAIN AND A SLOWER CLOCK DOMAIN IN WHICH ONE OF THE CLOCK DOMAINS IS BANDWIDTH LIMITED"**, of which We declare the following to be a full, clear and exact description:

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention is directed generally toward a method and apparatus for processing data, and in particular, the present invention provides a method and apparatus for transferring data between two clock domains. Still more particularly, the present invention provides a method and apparatus for ensuring data integrity when synchronizing a transfer of data between a slower clock domain and a faster clock domain.

2. Description of the Related Art:

Designs of computer systems and computer system architectures today can include the combination of one or more different subsystems with each subsystem having a different bus architecture. Subsystems are combined to facilitate the implementation of larger systems and typically known and standard subsystems are the ones selected for combining. By using known and standard subsystems, design time, manufacturing costs, design complexity, system maintenance and trouble shooting can all be reduced advantageously.

One standard bus architecture is the Peripheral Component Interconnect (PCI) bus standard. Computer systems can communicate with coupled peripherals using different bus standards including the PCI bus standard, or alternatively, using the Industry Standard Architecture (ISA) and Extended Industry Standard Architecture (EISA) bus standards. Recently, the IEEE 1394 serial communication standard has become a popular bus standard adopted by manufacturers of computer systems and peripheral components for its high speed and interconnection flexibilities. Each of the above communication standards communicates information (e.g., in data packets) at particular clock rates depending on the clock speed selected for the bus architecture.

In transferring or sharing data between different subsystems, data may be required to be synchronized because interconnected subsystems may not necessarily communicate or operate at the same clock frequency. With different bus architecture standards available within computer systems and communications systems, a computer device using one bus standard or "clock domain"

may be coupled to and communicate with another computer or device using a different bus standard having a different clock domain. Interface circuits are employed to synchronize data transfers between different clock domains.

One issue that must be addressed by these interface circuits is to ensure data integrity in the transfer of data from one clock domain to another clock domain. This problem is present in transferring data across an asynchronous interface in which one side of the interface has reached the limit of available bandwidth. Write and data valid signals generated by traditional synchronization techniques may not be able to guarantee valid data when one of the clock domains serviced by the interface is bandwidth limited. When a transfer occurs on every clock cycle, the bandwidth is limited on one side of the clock domain. The problem that arises is that this amount of time may be insufficient for holding the data in the registers and synchronizing the new data to the other clock domain. As a result, a portion of the data within the registers may not be valid while other portions of the data within the register are valid when the data is synchronized across the clock domains.

Thus, it would be advantageous to have an improved method and apparatus for ensuring data integrity in synchronizing between a slower clock domain and a faster clock domain when data is transferred between the clock domains on every clock cycle in the slower clock domain.

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SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for ensuring the integrity of data being transferred between two clock domains in which one clock domain is a faster clock domain than the other clock domain in which data is transferred on every clock signal from the slower clock domain. Data is received at a data collection or data capture unit for transfer to the second clock domain. The data received has a first data size and is stacked with additional data of the first data size to generate data having a second data size. For example, the first data size may be 16 bits while the second data size is 32 bits. Data is collected by the data capture unit in two or more banks of registers for transfer to the second clock domain. When two banks of registers are used, one bank of registers is being filled while the other bank of registers is passing data to the second clock domain. These two banks of registers provide two data paths to the synchronization logic for the second clock domain. This method and apparatus is especially advantageous when the limit of available bandwidth has been reached by one of the clock domains.

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BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a diagram illustrating components used in transferring data from one clock domain to another clock domain in accordance with a preferred embodiment of the present invention;

Figure 2 is a logic diagram of a data capture unit in accordance with a preferred embodiment of the present invention;

Figure 3 is a logic diagram of a synchronizer circuit in accordance with a preferred embodiment of the present invention; and

Figure 4 is a timing diagram illustrating signals used in passing data from one clock domain to another clock domain in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION

The description of the preferred embodiment of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention the practical application to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

With reference now to the figures and in particular with reference to **Figure 1**, a diagram illustrating components used in transferring data from one clock domain to another clock domain is depicted in accordance with a preferred embodiment of the present invention. In this example, data is transferred from clock domain **100** to clock domain **102**. In this example, data source **104** provides data using a bandwidth of 16 bits. Thus, the data size received by data capture unit **106** is 16 bits. Data capture unit **106** generates, in this example, data having a data size of 32 bits. This data is sent to synchronizer **108** for transfer to clock domain **102**.

In a preferred embodiment of the present invention, data capture unit **106** includes two banks of registers, bank **110** and bank **112**. Each of these banks of registers holds data having a data size of 32 bits in these examples. Data source **104** provides data having a data size of 16 bits. The data is stacked within the banks to form a 32 bit value. In actual operation, one bank of registers is being filled while data in the other bank of registers is being sent to synchronizer **108**. For example, when data is first sent to data capture unit **106** for transfer to clock domain **102**, data source **104** will provide data having a 16 bit data size to bank **110** to form a 32 bit block of data. When bank **110** is filled, data capture unit **106** will then fill bank **112** with data from data source **104** while the data stacked in **110** is passed to synchronizer **108**. Thereafter, bank **112** becomes filled with data. Data capture unit **106** then fills bank **110** with data and transfers the data within bank **112** to clock domain **102** through synchronizer **108**. As can be seen, the filling and transferring of data alternates between bank **110** and bank **112**. This feature of the present invention ensures that data being passed to clock domain **102** is stable while being able to

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support a data transfer on the occurrence of every clock pulse in clock domain 100. The stacking of data within the banks also provides for taking into account the limit of bandwidth within clock domain 100.

Although the depicted examples illustrate the use of two banks of registers, additional banks of registers may be used. For example, bank 114 may be added to receive and transfer data. The filling and transferring of data rotates between banks 110, 112, and 114, if three banks of registers are used. Additionally, the mechanism of the present invention may be applied to other data sizes other than 16 and 32 bit bus systems as illustrated in Figure 1. For example, clock domain 100 may employ a 32 bit bus while clock domain 102 employs a 64 bit bus. Alternatively, clock domain 100 may employ a 16 bit bus while clock domain 102 uses a 64 bit bus. The examples illustrate stacking the data such that the data size in the banks matches that of clock domain 102. The size of the stacked data is not required to equal that of the target clock domain, clock domain 102. For example, with a 16 bit data size in clock domain 100 and a 64 bit data size in clock domain 102, data may be stacked to a size of 48 bits instead of 64 bits for transfer to clock domain 102.

Turning next to Figure 2, a logic diagram of a data capture unit is depicted in accordance with a preferred embodiment of the present invention. Data capture unit 200 is an example of a data capture unit, which may be implemented as data capture unit 106 in Figure 1.

In this example, data capture unit 200 includes two banks of registers, bank 202 and bank 204. Each of these banks of registers is designed to receive 16 bit values of data as the data size and stack these values to form a 32 bit value as the data size for the target clock domain. Bank 202 includes multiplexer M1, multiplexer M2, D flip-flop D1, and D flip-flop D2. Bank 204 includes multiplexer M3, multiplexer M4, D flip-flop D3, and D flip-flop D4. A switch implemented using multiplexer M5 is used to select between bank 202 and bank 204 to transfer data to a synchronizer, such as synchronizer 108, in Figure 1.

Data is received at input 206 in multiplexer M2 and input 208 in multiplexer M2 from a data source, such as data source 104, in Figure 1. The data is received in a data size of 16 bits. Output 210 of multiplexer M1 is connected to input 212 of D flip-flop D1. Output 214 in D flip-flop D1 is connected to input 216 in multiplexer M1 to form a feedback loop as well as to input

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218 in multiplexer **M5**. Output 220 in multiplexer **M2** is connected to input 222 of D flip-flop **D2**. Output 224 of **D4** is connected to input 226 of multiplexer **M2**. Additionally, output 224 is connected to input 218 of multiplexer **M5**. Output 214 and output 224 are each 16 bits and are combined to form a data size of 32 bits into input 218 in multiplexer **M5**.

5 In bank 204, data having a data size of 16 bits may be received at input 227 and input 228 in multiplexer **M3** and multiplexer **M4**, respectively. Output 230 of multiplexer **M3** is connected to input 232 of D flip-flop **D3**. Output 234 in D flip-flop **D3** is connected to input 235 in multiplexer **M3** to form a feedback loop. Additionally, output 234 also is connected to input 218 in multiplexer **M5**. Next, output 236 in multiplexer **M4** is connected to input 238 of D flip-flop **D4**. Output 240 of **D4** is connected to input 242 of multiplexer **M4** and to input 218 of multiplexer **M5**. Output 234 and output 240 are each 16 bits and are combined to form a data size of 32 bits into input 218 in multiplexer **M5**.

The transfer of data is driven by a clock signal **clk1**, which is applied to clock inputs 242, 244, 246, and 248 in D flip-flops **D1**, **D2**, **D3**, and **D4**, respectively. Multiplexers **M1**, **M2**, **M3**, and **M4** may be enabled to pass data by the application of enable signals, **BankEnable** and **Hi16Enable**, which are applied to enable inputs 250, 252, 254, and 256 through AND gates **A1**, **A2**, **A3**, **A4**, and inverters **I1** and **I2**. Multiplexer **M5** is enabled by the application of the enable signal **BankEnable** to enable input 258. These gates and inverters are used to stack data within each bank as well as enable or select a bank to transfer data. When the signal **BankEnable** is high or a logic 1, bank 202 fills with data while bank 204 passes data to multiplexer **M5**. When the signal **BankEnable** transitions to a low or a logic 0, bank 204 fills with data while bank 202 passes data to multiplexer **M5**. The enable signal **Hi16Enable** is used to stack data in the bank that is being filled with data. For example, if bank 202 is being filled with data, a high signal or a logic 1 causes the top 16 bits of the data value being stacked to be received by multiplexer **M1**.
 20 A low signal or a logic 0 causes the lower 16 bits to be received by multiplexer **M2**. Thus, in addition to stacking data to form a desired data size, data capture unit 200 provides two paths for transferring data to a target clock domain through bank 202 and bank 204.

25 Multiplexer **M5** selects data received from D flip-flop **D1**, D flip-flop **D2**, or from D flip-flop **D3** or D flip-flop **D4** to generate a signal **Clk1DataOut**, which has a 32 bit data size in this

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example for transfer to a synchronizer. A timing diagram is provided in **Figure 4** and described below to illustrate the operation of data capture unit **200**.

Depending on the particular implementation, additional banks may be employed within data capture unit **200**. Further, the particular data sizes and components used are not meant as limitations to the implementation of the present invention. For example, the stacking of data may be implemented using three or more sets of multiplexers and flip-flops instead of the two depicted in banks **202** and **204**. In addition, the number of registers in the bank is a function of how many bits are being stacked. For example, in **Figure 2**, banks **202** and **204** each contain two multiplexers and two flip-flops to stack 16 bit portions of data into 32 bit portions. If the data is being received in 32 bit portions and is being sent out as 32 bit portions, then a bank would only require a single multiplexer and a single flip-flop. As a further example, if 16 bit portions of data are being stacked into 48 bit portions of data, each of these banks would contain three multiplexers and three flip-flops. Of course, other types of logic components may be used to achieve the same results as banks **202** and **204**. Turning next to **Figure 3**, a logic diagram of a synchronizer circuit is depicted in accordance with a preferred embodiment of the present invention. Synchronizer circuit **300** may be implemented in synchronizer **108** in **Figure 1** to synchronize the transfer of data from one clock domain to another clock domain.

Synchronizer circuit **300** includes D flip-flop **F1**, D flip-flop **F2**, D flip-flop **F3**, D flip-flop **F4**, D flip-flop **F5**, D flip-flop **F6**, D flip-flop **F7**, and D flip-flop **F8** and exclusive OR (XOR) gate **X1**. D flip-flops **F1** and **F2** are used to send data to the target clock domain, such as clock domain **102** in **Figure 1**. D flip-flops **F1-F8** and XOR gate **X1** are used to generate a valid pulse, **Clk2DataEnable** to indicate that the data, **Clk2Data** is valid. D flip-flop **F1** receives **Clk1DataOut** from multiplexer **M5** in **Figure 2** at input **302**. The output **304** of D flip-flop **F1** is connected to input **306** of D flip-flop **F2**. Clock input **308** and **310** receive clock signal **clk2**, which is the clock signal from the target domain to drive passing of the data **Clk2Data**, which has a data size of 32 bits in this example. D flip-flop **F3** receives a signal **Hi16Enable** signal at input **312**. Output **314** in D flip-flop **F3** is connected to input **316** in D flip-flop **F4**. Output **314** generates a **Hi16Q1** signal as an output. Signal **Hi16Q2** is generated by output **318** in D flip-flop **F4**. This output is connected to clock input **320** in D flip-flop **F5**. The **Hi16Q2** signal as an

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output is received at clock input 320 in D flip-flop F5 for use as a clock signal. Output 322 of D flip-flop F5 is connected to input 324 to form a feedback loop. Output 326 in D flip-flop F5 generates a toggle signal received by input 328 in D flip-flop F6. Toggle signal toggleQ1 is generated at output 330 in D flip-flop F6 with this output being connected to input 332 in D flip-flop F7. Output 334 in D flip-flop F7 is connected to input 336 in D flip-flop F8. Output 338 is connected to XOR gate X1, which generates an enable signal Clk2DataEnable. An additional input into XOR gate X1 is the signal toggleQ2, which is generated at output 334 at D flip-flop F7. D flip-flops F6, F7, and F8 receive clock signal clk2 at clock inputs 340, 342, and 344, while D flip-flops F3 and F4 receive clock signal clk1 at clock inputs 346 and 348.

Synchronizer circuit 300 is only intended as an example of a synchronizer circuit that may be used to synchronize the transfer of data and is not intended as a limitation to the type of synchronizer circuit that may be employed. Any known synchronization circuit or technique may be used depending on the particular implementation. Operation of synchronization circuit 300 is provided in more detail in the timing diagram in Figure 4 as described below.

Turning next to Figure 4, a timing diagram illustrating signals used in passing data from one clock domain to another clock domain are depicted in accordance with a preferred embodiment of the present invention. In this example, the signals illustrated in timing diagram 400 illustrate input and output signals used to transfer data in data capture unit 200 in Figure 200 and synchronizer circuit 300 in Figure 3. First, signal **resetb** is used to clear all of the D flip-flops in data capture unit 200 and synchronizer circuit 300. Next, clock signal **clk2** and clock signal **clk1** represent the clock signals in the two different clock domains. As can be seen, clock signal **clk2** is faster than clock signal **clk1**. Data signal **ClkDataIn** represents data from a data source, such as data source 104 in Figure 1. In these examples, data signal **ClkDataIn** includes data having a 16 bit data size. Next, enable signal **Hi16Enable** is the enable signal used to fill the top or bottom 32 bits in a bank of registers, such as in multiplexers M1 and M2 in bank 202 in Figure 2. Enable signal **BankEnable** is used to enable a bank, such as bank 202 or 204 to send data through multiplexer M5. Signals **Hi16Q1** and **Hi16Q2** are valid pulses generated by D flip-flop F3 and D flip-flop F4, respectively. Toggle signals **toggle**, **toggleQ1**, **toggleQ2**, and **toggleQ3** are generated by D flip-flops F5, F6, F7, and F8, respectively, in the synchronization

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circuit depicted in **Figure 3**.

Data signal **Clk2Data** is the data transferred to the target clock domain, and enable signal **Clk2DataEnable** is the signal used to indicate when the data is valid. The signal **Clk1DataOut** is generated by multiplexer **M5** in data capture unit **200** and received by D flip-flop **F1** in synchronization circuit **300**. The data signals **Data1** and **Data2** represent the data output by bank **204** and bank **202**, respectively in data capture unit **200** in **Figure 2**.

These signals illustrate the stacking of data into the different banks in data capture unit **200**. In this example, data signal **Clk1DataIn** includes data **401-411**. Data **401** is stored in multiplexer **M3** while data **402** is stored in multiplexer **M4**. As can be seen, the signal **Hi16Enable** allows for the enablement of one of these two multiplexers in bank **204**. This signal performs a similar function with respect to multiplexer **M1** and multiplexer **M2** in bank **202** when data is being stacked in this bank. When the data is stacked, it is generated as data signal **Data1** in a 32 bit data size by bank **204**. A similar function occurs with the generation of data signal **Data2** from bank **202**. When enable signal **BankEnable** is high, data signal **Clk1DataOut** generates data from bank **204**. When this enable signal goes low, data signal **Clk1DataOut** generates data from bank **202**. As can be seen, data is clocked into the data capture unit on every clock signal **clk1**, which represents the slower clock domain in this example. The reuse of reference numbers **401-411** from **Clk1DataIn** in other data signals in **Figure 4** represents the same corresponding data in these other data signals.

Thus, the present invention provides an improved method and apparatus for transferring data from one clock domain to another clock domain. The mechanism of the present invention provides two data paths, which feed the synchronization logic, such as synchronization circuit **300** in **Figure 3**. While one bank of registers is being filled with data from the first clock domain, the other bank of registers passes data to the second clock domain. The mechanism of the present invention stacks the data into a data size for use in the second clock domain. Through this mechanism, data integrity is ensured when synchronizing the transfer of data between a slower clock domain and a faster clock domain when one of the interfaces is bandwidth limited.

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The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art.

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